# Key points

Memoryless polynomial – at least in textbook form – cannot model AMPM

Cannot use baseband equivalents to model RF harmonics (I think this means we can’t use baseband equivalent models if we want to generate and analyze RF harmonics)

Can use baseband equivalents to model baseband harmonics

Cannot use AMAM to model any harmonics

# RF memoryless polynomial model

**RF model:**

A complex IQ waveform, at RF, is given by

and .

The RF memoryless polynomial model is

Plugging in,

We have the fundamental (desired), spectral regrowth, IM2, and RF harmonics.

**Lowpass equivalent model:**

Let’s translate and to their lowpass equivalents (with as the center frequency):

The terms with cannot be written in terms of . For the remaining terms,

## Complex waveform simulation

At RF, a complex waveform in an IQ transceiver takes the form of

Where and . Passing through the RF nonlinear model yields the desired signal, spectral regrowth (IM3), IM2, and RF harmonics:

Since the RF model is the true model and is independent of input waveform, the coefficients and are given by the RF two-tone test.

The baseband equivalent signal is . However, because contains both -centered terms (signal and spectral regrowth) and a DC-centered term (IM2), when we derive the baseband equivalent model, we must carefully consider the amplitudes of the terms. (Note that RF harmonics cannot be modeled with baseband equivalents).

In the RF model, we must downconvert the -centered terms:

Therefore, the downconverted output is

While it may be tempting to multiply by 2 to “clean up” the ½ factor in the downconversion, this is incorrect since it halves the relative power of IM2. These nonlinear models are based on input intercept points, which means all terms must experience the same gain.

Then the baseband equivalent model is

Typically, to determine the minimum spec for the intercept points, the average power of one tone in the two-tone test is set equal to the target power of the complex waveform (e.g. OFDM).

## Two-tone simulation

**RF model:**

The output of the model is the fundamental, IM2, and IM3 (spectral regrowth):

IIP2 and IIP3:

These intercept definitions are peak amplitude of one tone.

Typically, IIP2 and IIP3 are specified as average power of one tone.

**Baseband equivalent model:**

The baseband equivalent input signal is

What are the baseband equivalents of the RF output?

What about the second-order term? It’s already a baseband signal, so there’s no conversion. However, it’s important to scale this term by 2 so its amplitude relative to the fundamental remains the same.

If we look only at the positive frequencies (since all of the signals are real), then

The baseband equivalent signal is

In the baseband equivalent model, we have

1. Fundamental:
2. IM2:
3. IM3:

Then the baseband equivalent model is

Let’s calculate the intercepts and coefficients using the RF model:

1. 2nd order:
2. 3rd order:

Typically, input power, , and intercepts, and , are given as average power in dBm of one RF tone. For conversion to amplitudes, we have

Where . factor comes from rms-to-peak conversion:

From the RF model,

When simulating using the RF model instead of the baseband equivalent model, you must ensure that spurs do not land on top of each other. For example, RF harmonics may alias back into the intermodulation products of interest.

## Cascaded IIP3

Let’s say your signal passes through multiple nonlinear systems, e.g.

For two stages,

Keeping only fundamental and 3rd-order terms, we have

Breaking down the terms, we have

1. : fundamental
2. : 3rd-order term from the first stage
3. : 3rd-order term from the second stage
4. : 2nd-order mixing in the second stage of (2nd-order term from first stage, fundamental)

Since and are generated by 3rd-order nonlinearity, these products are inband. However, involves mixing components at twice the fundamental, which are out of band. If we assume and add in phase while is suppressed, and we apply the equation for to the cascaded system response, we have

Extending to any number of stages, we have

Where is the IIP3 of the nth stage and is the fundamental voltage gain of the nth stage.

Large terms dominate the right-hand-side and in turn dominate the overall system . In an amplification chain, this means nonlinearity of later stages is more important than earlier stages. The of a stage is reduced by the gains of the previous stages:

## Cascaded IIP2 (TBD)

# Baseband amplifier as a memoryless polynomial

The derivation for a baseband amplifier is slightly different. Let , , and . Then

The complex signal after the baseband nonlinearity is :

The output terms are the signal, spectral regrowth, BBHD2, CIM3, and 2nd-order DC distortion.

As in the RF amplifier derivation, the strength of the nonlinear terms is a function only of the envelope amplitude .

## Input intercept points?

## CIM3 (TBD)

Since CIM3 tends to be relatively low, can I just model it as ?

# AMAM-AMPM models (TBD)

Baseband equivalent

Instead of specifying nonlinear orders, specify a transfer curve

## Rapp

AMAM nonlinear model:

AMAM can only model terms like , like spectral regrowth in the RF amplifier.

It cannot model the RF harmonic in the RF amplifier or CIM3 in the baseband amplifier.

Rapp is one way of modeling AMAM:

Where is the linear amplifier gain, is the smoothness factor, and is the output saturation level.

## Saleh

AMPM nonlinear model:

Saleh is one way of modeling AMPM:

Where and are parameters to choose.

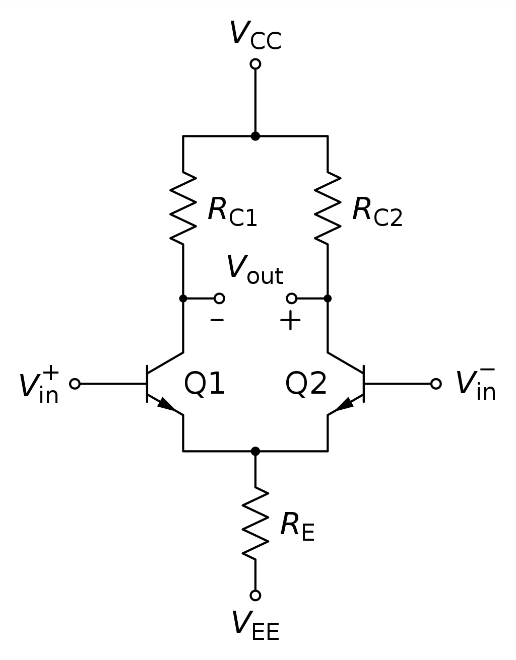
## Rapp-Saleh

AMAM-AMPM nonlinear model:

Rapp and Saleh can be combined to model AMAM-AMPM:

# Differential circuits to suppress even-order nonlinearity

We typically use differential circuits to suppress the even-order nonlinear terms. In a differential amplifier, the inputs are driven by signals of the same magnitude but opposite polarity. If the output is differential, the output is the difference between positive and negative terminals.



In our RF memoryless polynomial model, if the inputs are differential and driven by , we have

The 2nd-order term is cancelled if the “positive” and “negative” amplifiers are identical.

The same derivation applies separately to and paths in the baseband memoryless polynomial model.

# Cross modulation (TBD)

is desired, and are the interferers. Third-order nonlinearity will generate components at and . If is small, then the distortion products will be close to the signal frequency . This is actually the triple beat test.

# Triple beat (TBD)

# Dynamic nonlinear models

GMP, DDR/Volterra, Hammerstein, Weiner